

# Mendelelian Genetics

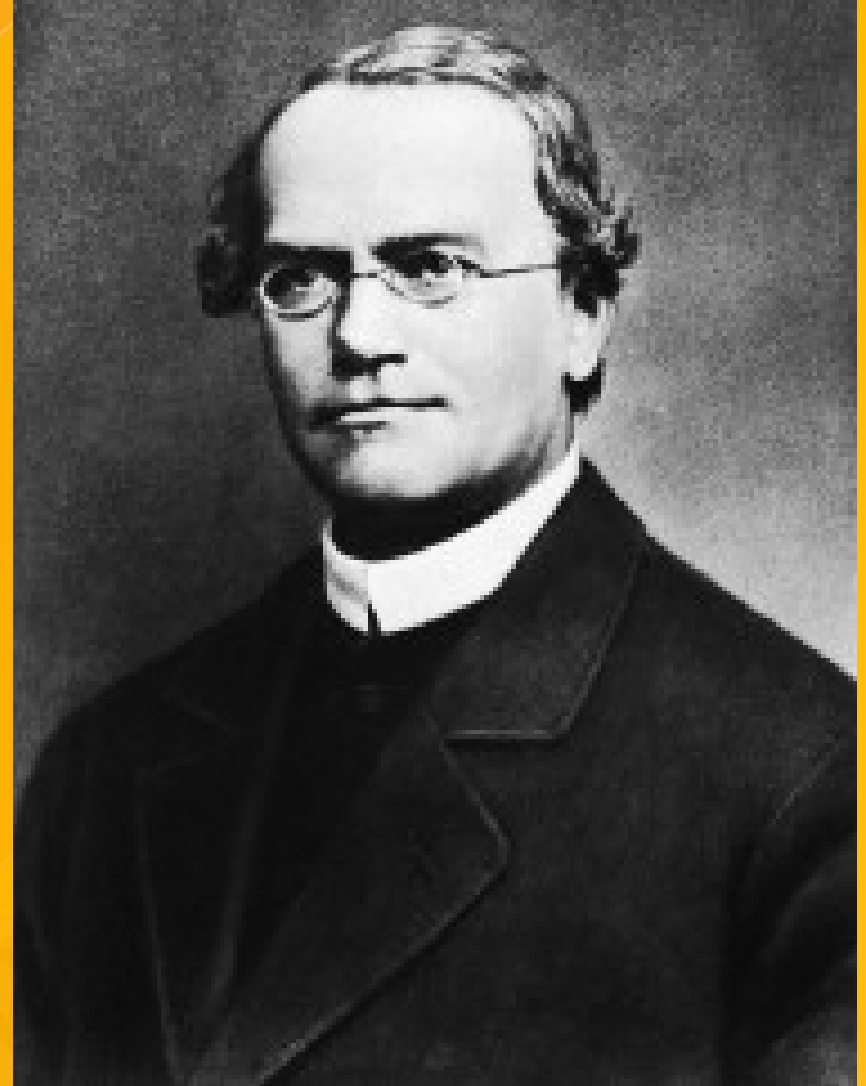
# Gregor Mendel (1822-1884)

Responsible  
for the Laws  
governing  
Inheritance of  
Traits



# Gregor Johann Mendel

- Austrian monk
- Studied the inheritance of traits in pea plants
- Developed the laws of inheritance
- Mendel's work was not recognized until the turn of the 20th century

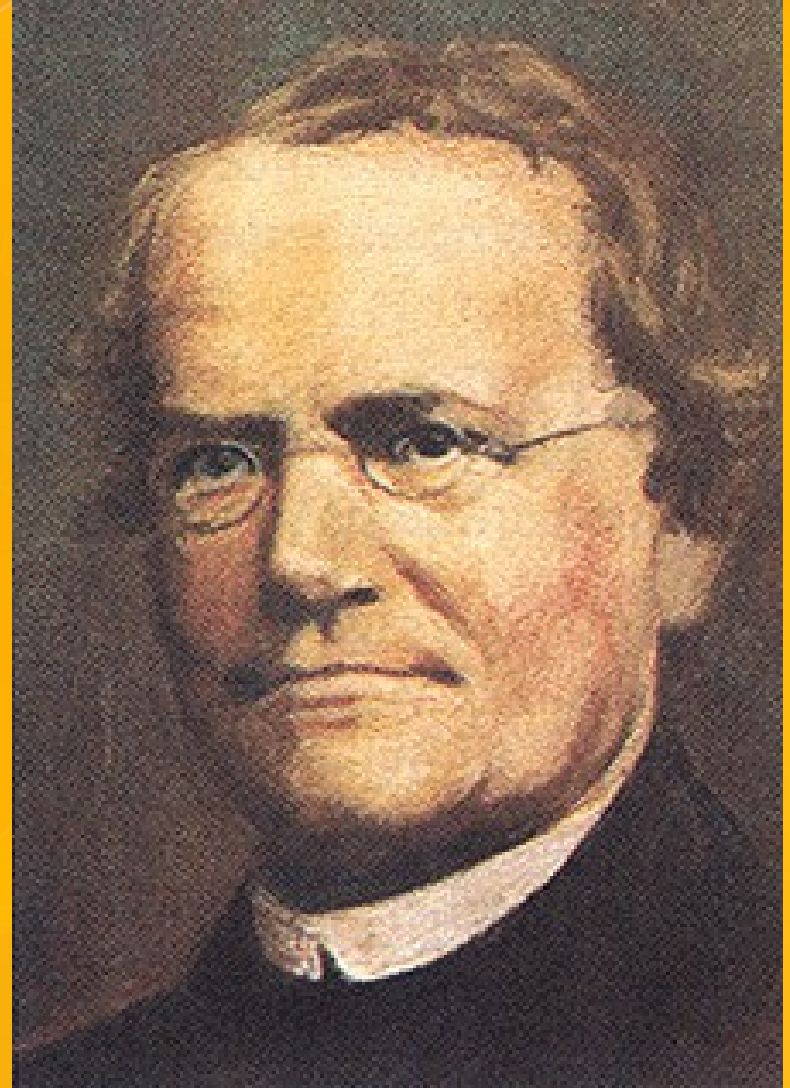


# Gregor Johann Mendel

■ Between 1856 and 1863, Mendel cultivated and tested some 28,000 pea plants

■ He found that the plants' offspring retained traits of the parents

■ Called the "Father of Genetics"





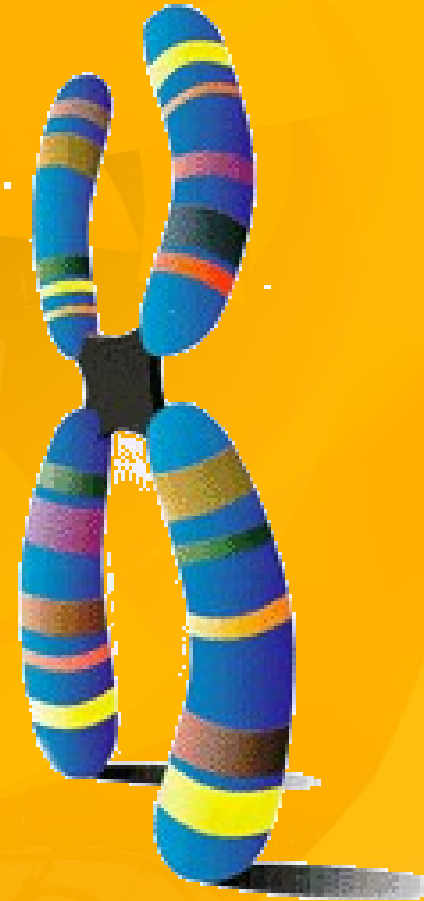


**Site of  
Gregor  
Mendel's  
experimental  
garden in the  
Czech  
Republic**

# Particulate Inheritance

- Mendel stated that physical traits are inherited as “particles”

- Mendel did not know that the “particles” were actually **Chromosomes & DNA**





# Genetic Terminology

- **Trait** - any characteristic that can be passed from parent to offspring
- **Heredity** - passing of traits from parent to offspring
- **Genetics** - study of heredity

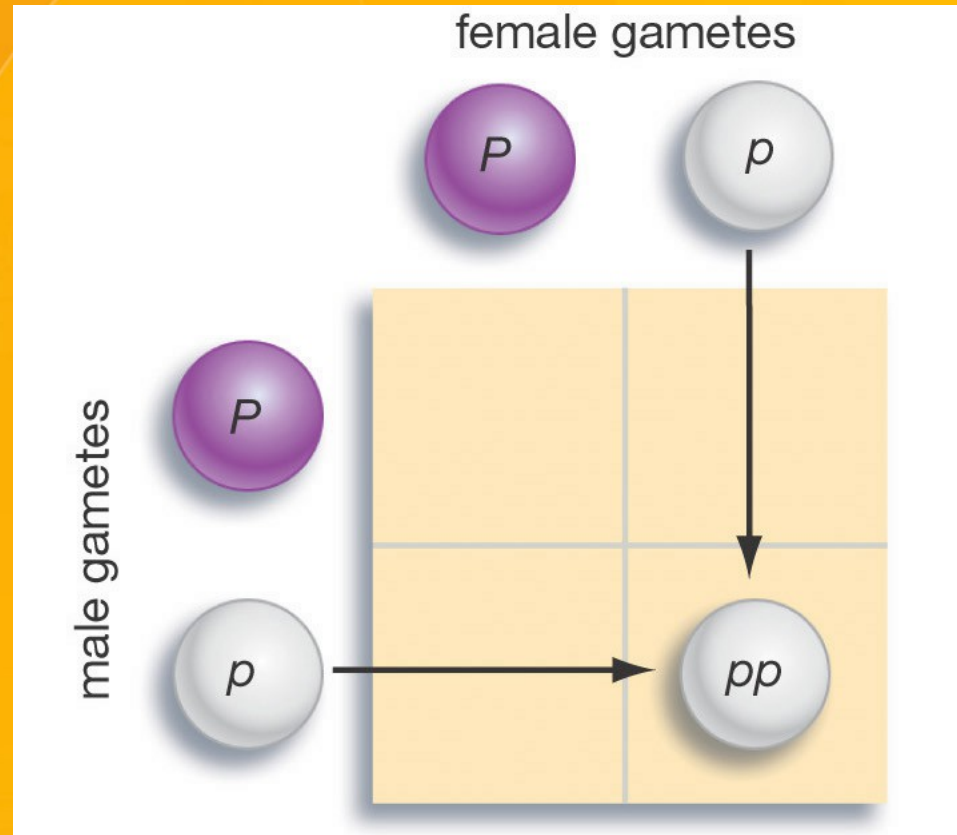
# Types of Genetic Crosses

- **Monohybrid cross** - cross involving a single trait  
e.g. flower color
- **Dihybrid cross** - cross involving two traits  
e.g. flower color & plant height



# Punnett Square

Used to help  
solve genetics  
problems



# How to Make a Punnett Square

Punnett squares allow geneticists to predict the possible genotypes and phenotypes of offspring.

In this example, both parents are heterozygous for yellow-pea allele ( $Yy$ ).

Parent 1



Parent 2



## 1 Make the grid

Place the alleles of the gametes of one parent along the top of a grid and those of the other parent along the left-hand side.

$Yy$	$Y$	$y$
$Y$		
$y$		

## 2 Fill in the grid





Combine the parent alleles inside the boxes. The letters show the genotypes of the offspring.

	$Y$	$y$
$Y$	$YY$	$Yy$
$y$	$Yy$	$yy$

The genotype ratio is 1:2:1, meaning 1  $YY$ , 2  $Yy$ , 1  $yy$ .

## 3 Fill in the offspring

Use the Law of Dominance to determine the phenotypes and phenotype ratio of the offspring.

	$Y$	$y$
$Y$	 $YY$	 $Yy$
$y$	 $Yy$	 $yy$

The phenotype ratio is 3:1, meaning 3 yellow peas to 1 green pea.

# Designer "Genes"

- **Alleles** - two forms of a gene (dominant & recessive)
- **Dominant** - stronger of two genes expressed in the hybrid; represented by a **capital letter (R)**
- **Recessive** - gene that shows up less often in a cross; represented by a **lowercase letter (r)**

# More Terminology

- **Genotype** - gene combination for a trait (e.g. RR, Rr, rr)
- **Phenotype** - the physical feature resulting from a genotype (e.g. red, white)





# Genotype & Phenotype in Flowers

Genotype of alleles:

**R** = red flower

**r** = yellow flower

All genes occur in pairs, so **2 alleles** affect a characteristic

Possible combinations are:

Genotypes

**RR**

**Rr**

**rr**

Phenotypes

**RED**

**RED**

**YELLOW**



# Genotypes

- **Homozygous** genotype - gene combination involving 2 dominant or 2 recessive genes (e.g.  $RR$  or  $rr$ ); also called **pure**
- **Heterozygous** genotype - gene combination of one dominant & one recessive allele (e.g.  $Rr$ ); also called **hybrid**



# Genes and Environment Determine Characteristics



# Mendel's Pea Plant Experiments





# Why peas, *Pisum sativum*?

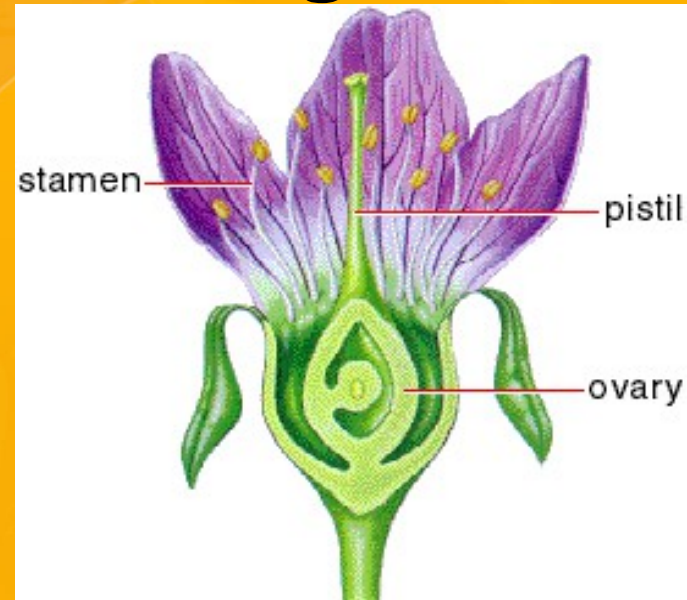
- Can be grown in a small area
- Produce lots of offspring
- Produce pure plants when allowed to self-pollinate several generations
- Can be artificially cross-pollinated



# Reproduction in Flowering Plants

**Pollen contains sperm**  
**Produced by the stamen**

**Ovary contains eggs**  
**Found inside the flower**



**Pollen carries sperm to the eggs for fertilization**

*Self-fertilization can occur in the same flower*

*Cross-fertilization can occur between flowers*

# Mendel's Experimental Methods

Mendel **hand-pollinated** flowers using a **paintbrush**

He could **snip the stamens** to prevent self-pollination

Covered each flower with a cloth bag

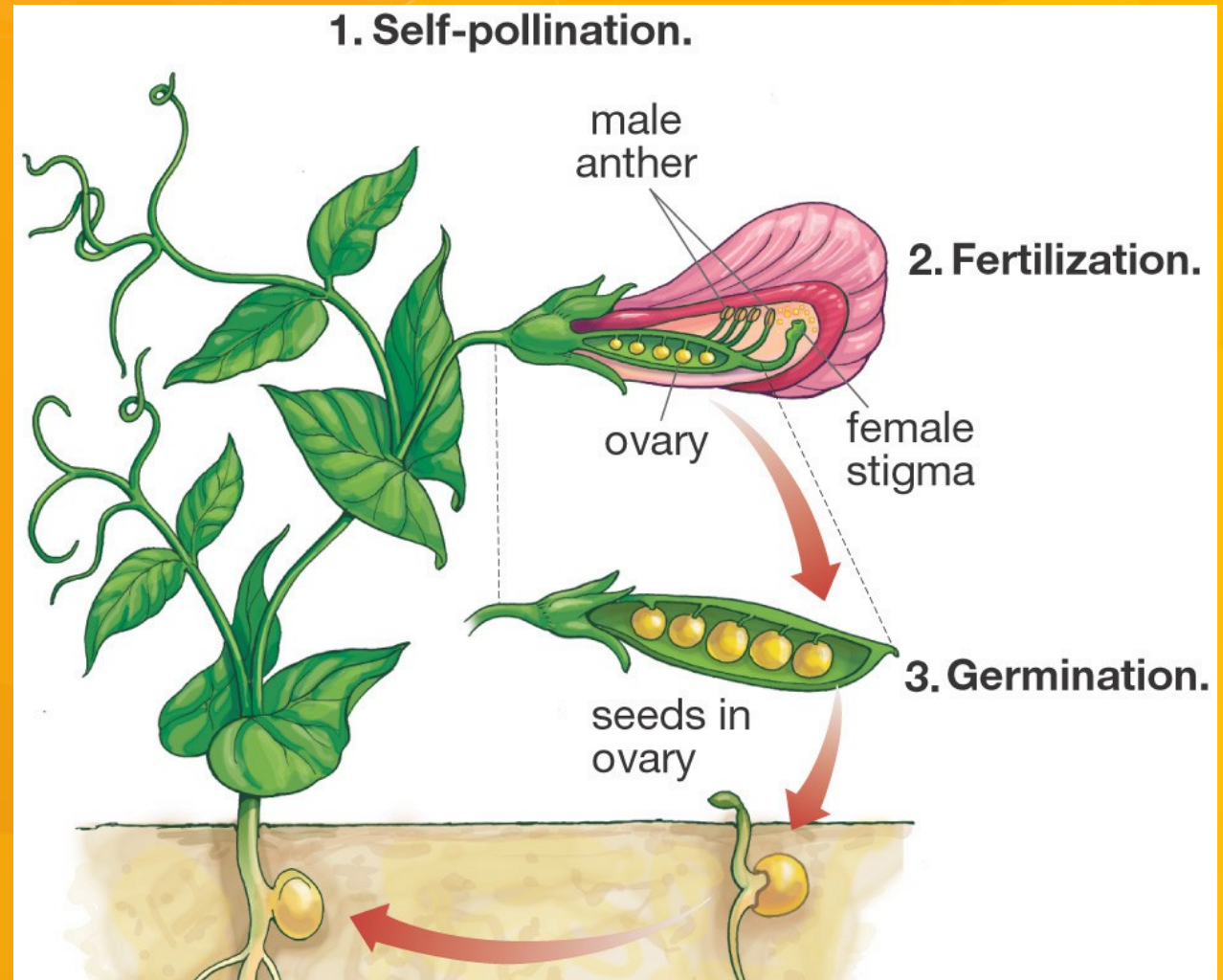
He traced traits through the **several generations**





# How Mendel Began

Mendel produced **pure** strains by allowing the plants to **self-pollinate** for several generations





# Eight Pea Plant Traits

**Seed shape** --- Round (R) or Wrinkled (r)

**Seed Color** ---- Yellow (Y) or Green (y)

**Pod Shape** --- Smooth (S) or wrinkled (s)

**Pod Color** --- Green (G) or Yellow (g)









**Seed Coat Color** --- Gray (G) or White (g)

**Flower position** --- Axial (A) or Terminal (a)

**Plant Height** --- Tall (T) or Short (t)

**Flower color** --- Purple (P) or white (p)

**Table 11.1 Pea-Plant Characters Studied by Mendel**

Character studied	Dominant trait	Recessive trait
Seed shape	smooth 	wrinkled 
Seed color	yellow 	green 
Pod shape	inflated 	wrinkled 
Pod color	green 	yellow 

Flower color

purple



white



Flower position

on stem



at tip



Stem length

tall




dwarf





# Mendel's Experimental Results

**Table 11.2 Ratios of Dominant to Recessive in Mendel's Plants**

Dominant trait	Recessive trait	Ratio of dominant to recessive in F <sub>2</sub> generation
Smooth seed	Wrinkled seed	2.96:1 (5,474 smooth, 1,850 wrinkled)
Yellow seed	Green seed	3.01:1 (6,022 yellow, 2,001 green)
Inflated pod	Wrinkled pod	2.95:1 (882 inflated, 299 wrinkled)
Green pod	Yellow pod	2.82:1 (428 green, 152 yellow)
Purple flower	White flower	3.14:1 (705 purple, 224 white)
Flower on stem	Flower at tip	3.14:1 (651 along stem, 207 at tip)
Tall stem	Dwarf stem	2.84:1 (787 tall plants, 277 dwarfs)
	<b>Average ratio, all traits:</b>	<b>3:1</b> 

# Did the observed ratio match the theoretical ratio?

The theoretical or expected ratio of plants producing round or wrinkled seeds is **3 round :1 wrinkled**

Mendel's observed ratio was 2.96:1

The discrepancy is due to **statistical error**

The **larger the sample** the more nearly the results approximate to the theoretical ratio

# Generation "Gap"

**Parental  $P_1$  Generation** = the parental generation in a breeding experiment.

**$F_1$  generation** = the first-generation offspring in a breeding experiment. (1st filial generation)

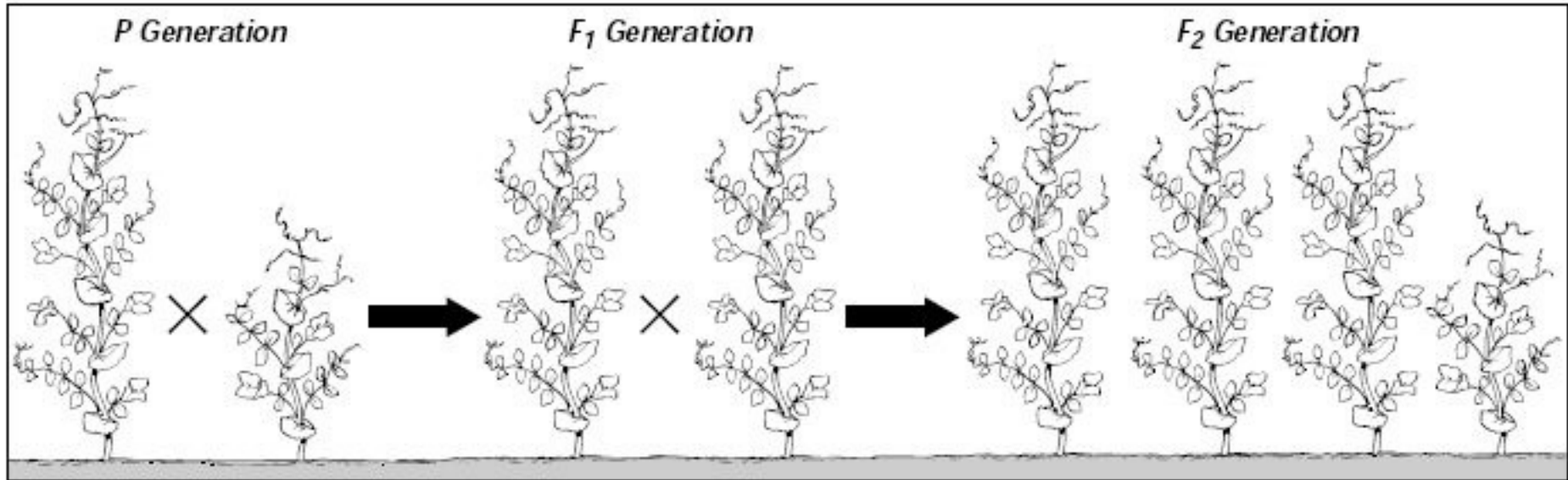
From breeding individuals from the  $P_1$  generation

**$F_2$  generation** = the second-generation offspring in a breeding experiment. (2nd filial generation)

From breeding individuals from the  $F_1$  generation



# Following the Generations



**Cross 2  
Pure  
Plants**

**TT x tt**

**Results  
in all  
Hybrids**

**Tt**

**Cross 2 Hybrids  
get  
3 Tall & 1 Short**

**TT, Tt, tt**

# Monohybrid Crosses

# P<sub>1</sub> Monohybrid Cross

Trait: Seed Shape

Alleles: **R** - Round      **r** - Wrinkled

Cross: **Round** seeds      x      **Wrinkled** seeds  
                 **RR**                      x                      **rr**

	<b>r</b>	<b>r</b>
<b>R</b>	Rr	Rr
<b>R</b>	Rr	Rr

Genotype: **Rr**

Phenotype: **Round**

Genotypic  
Ratio: **All alike**

Phenotypic  
Ratio: **All alike**



# **P<sub>1</sub> Monohybrid Cross Review**

- Homozygous dominant x Homozygous recessive
- Offspring all Heterozygous (hybrids)
- Offspring called F<sub>1</sub> generation
- Genotypic & Phenotypic ratio is **ALL ALIKE**

# F<sub>1</sub> Monohybrid Cross

Trait: Seed Shape

Alleles: **R** - Round      **r** - Wrinkled

Cross: **Round** seeds      x      **Round** seeds  
                                 **Rr**                                      **Rr**

	<b>R</b>	<b>r</b>
<b>R</b>	<b>RR</b>	<b>Rr</b>
<b>r</b>	<b>Rr</b>	<b>rr</b>

Genotype: **RR, Rr, rr**

Phenotype: **Round & wrinkled**

G.Ratio: **1:2:1**

P.Ratio: **3:1**

# **F<sub>1</sub> Monohybrid Cross Review**

- Heterozygous x heterozygous
- **Offspring:**
  - 25% Homozygous dominant **RR**
  - 50% Heterozygous **Rr**
  - 25% Homozygous Recessive **rr**
- Offspring called **F<sub>2</sub> generation**
- Genotypic ratio is **1:2:1**
- Phenotypic Ratio **is 3:1**



# What Do the Peas Look Like?

Some of these peas have a smooth texture, while others are wrinkled.



# ...And Now the Test Cross

Mendel then crossed a pure & a hybrid from his  $F_2$  generation

This is known as an  $F_2$  or test cross

There are two possible testcrosses:

Homozygous dominant x Hybrid

Homozygous recessive x Hybrid

# F<sub>2</sub> Monohybrid Cross (1<sup>st</sup>)

Trait: Seed Shape

Alleles: **R** - Round      **r** - Wrinkled

Cross: **Round** seeds      x      **Round** seeds  
                                 **RR**                      x                      **Rr**

	<b>R</b>	<b>r</b>
<b>R</b>	<b>RR</b>	<b>Rr</b>
<b>R</b>	<b>RR</b>	<b>Rr</b>

Genotype: **RR, Rr**

Phenotype: **Round**

Genotypic  
Ratio: **1:1**

Phenotypic  
Ratio: **All alike**



# F<sub>2</sub> Monohybrid Cross (2nd)

Trait: Seed Shape

Alleles: **R** - Round    **r** - Wrinkled

Cross: **Wrinkled** seeds x **Round** seeds

**rr**                      x                      **Rr**

	<b>R</b>	<b>r</b>
<b>r</b>	<b>Rr</b>	<b>rr</b>
<b>r</b>	<b>Rr</b>	<b>rr</b>

Genotype: **Rr**, **rr**

Phenotype: **Round & Wrinkled**

G. Ratio: **1:1**

P. Ratio: **1:1**

# F<sub>2</sub> Monohybrid Cross Review

- Homozygous x heterozygous(hybrid)
- **Offspring:**
  - 50% Homozygous **RR** or **rr**
  - 50% Heterozygous **Rr**
- Phenotypic Ratio is **1:1**
- Called **Test Cross** because the offspring have **SAME** genotype as parents

# Practice Your Crosses

Work the  $P_1$ ,  $F_1$ , and both  
 $F_2$  Crosses for each of the  
other Seven Pea Plant  
Traits

# Mendel's Laws



# Results of Monohybrid Crosses

Inheritable **factors** or **genes** are responsible for all heritable characteristics

**Phenotype** is based on **Genotype**

**Each trait** is based on **two genes**, one from the mother and the other from the father

True-breeding individuals are **homozygous** ( **both alleles**) are the same

# Law of Dominance

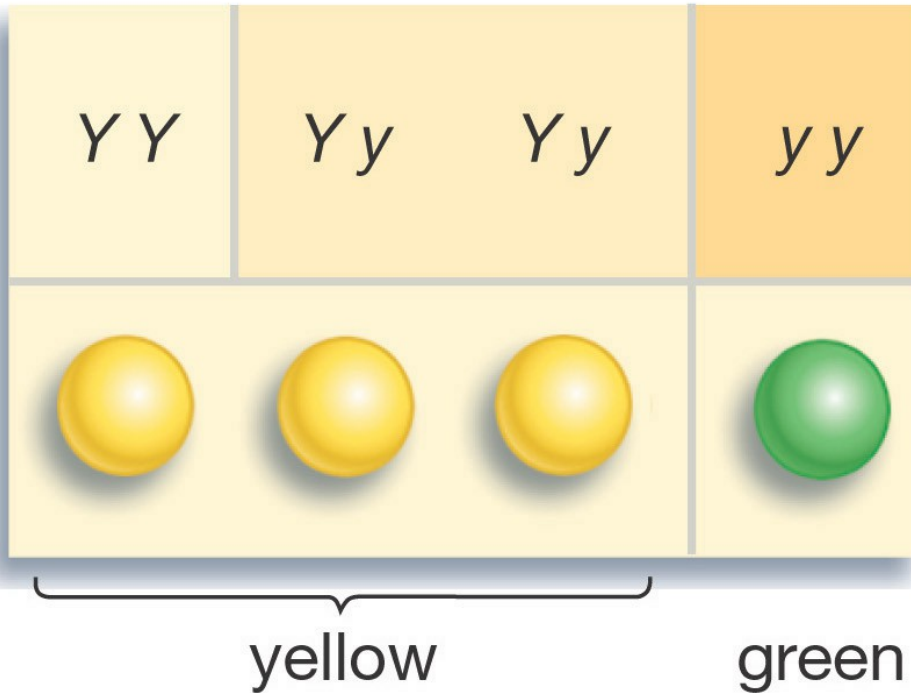


In a cross of parents that are **pure for contrasting traits**, only one form of the trait will appear in the next generation.

All the offspring will be heterozygous and express only the **dominant trait**.

**RR x rr yields all Rr (round seeds)**

# Law of Dominance



Three genotypes yield . . .

two phenotypes.

# Law of Segregation

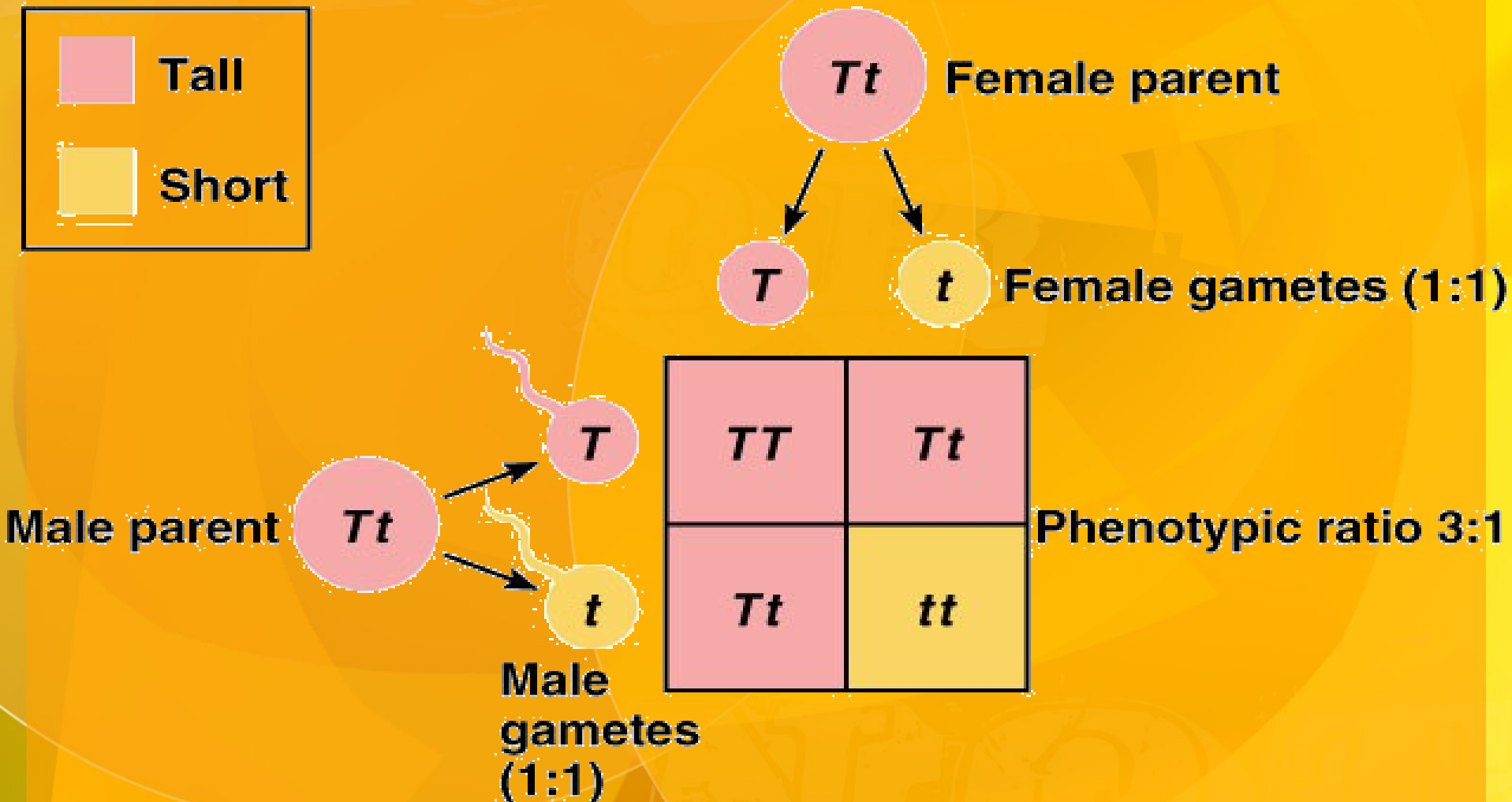
During the **formation** of gametes (eggs or sperm), the **two alleles** responsible for a trait **separate** from each other.

Alleles for a trait are then **"recombined"** at fertilization, producing the genotype for the traits of the offspring.



# Applying the Law of Segregation

 Tall  
 Short



# Law of Independent Assortment

Alleles for *different* traits are distributed to sex cells (& offspring) independently of one another.

This law can be illustrated using *dihybrid crosses*.

# Dihybrid Cross

A breeding experiment that tracks the inheritance of two traits.

Mendel's "Law of Independent Assortment"

- a. Each pair of alleles segregates independently during gamete formation
- b. Formula:  $2^n$  ( $n$  = # of heterozygotes)

## Question:

How many gametes will be produced for the following allele arrangements?

Remember:  $2^n$  ( $n$  = # of heterozygotes)

1. RrYy

2. AaBbCCDd

3. MmNnOoPPQQRrssTtQq



# Answer:

1.  $RrYy$ :  $2^n = 2^2 = 4$  gametes

$RY$      $Ry$      $rY$      $ry$

2.  $AaBbCCDd$ :  $2^n = 2^3 = 8$  gametes

$ABCD$      $ABCd$      $AbCD$      $AbCd$   
 $aBCD$      $aBCd$      $abCD$      $abCd$

3.  $MmNnOoPPQQRrssTtQq$ :  $2^n = 2^6 = 64$   
gametes

# Dihybrid Cross

**Traits: Seed shape & Seed color**

**Alleles:** R round  
r wrinkled  
Y yellow  
y green

RrYy x RrYy

RY Ry rY ry

RY Ry rY ry

**All possible gamete combinations**

# Dihybrid Cross

	R $Y$	R $y$	r $Y$	r $y$
R $Y$				
R $y$				
r $Y$				
r $y$				

# Dihybrid Cross

	<b>RY</b>	<b>Ry</b>	<b>rY</b>	<b>ry</b>
<b>RY</b>	RRYY	RRYy	RrYY	RrYy
<b>Ry</b>	RRYy	RRyy	RrYy	Rryy
<b>rY</b>	RrYY	RrYy	rrYY	rrYy
<b>ry</b>	RrYy	Rryy	rrYy	rryy

Round/Yellow: 9

Round/green: 3

















wrinkled/Yellow: 3

wrinkled/green: 1

**9:3:3:1** phenotypic ratio



# Dihybrid Cross

	RY	Ry	rY	ry
RY	 RRYY	 RRYy	 RrYY	 RrYy
Ry	 RRYy	 RRyy	 RrYy	 Rryy
rY	 RrYY	 RrYy	 rrYY	 rrYy
ry	 RrYy	 Rryy	 rrYy	 rryy

Round/Yellow: 9  
 Round/green: 3  
 wrinkled/Yellow: 3  
 wrinkled/green: 1

**9:3:3:1**

# Test Cross

A mating between an individual of unknown genotype and a homozygous recessive individual.

Example:  $bbC\_ \times bbcc$

$BB$  = brown eyes

$Bb$  = brown eyes

$bb$  = blue eyes

$CC$  = curly hair

$Cc$  = curly hair

$cc$  = straight hair

	$bC$	$b\_$
$bc$		

# Test Cross

Possible results:

	bC	b <u>C</u>
bc	bbCc	bb <u>C</u> c

or

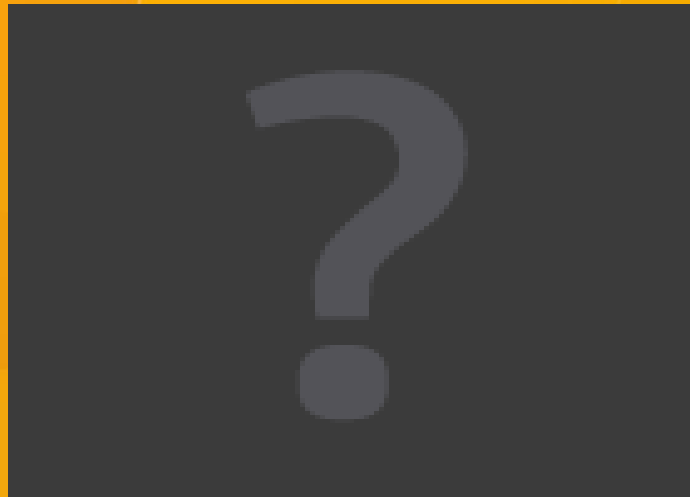
	bC	b <u>c</u>
bc	bbCc	bb <u>c</u> c

# Summary of Mendel's laws

LAW	PARENT CROSS	OFFSPRING
DOMINANCE	$TT \times tt$ tall x short	100% $Tt$ tall
SEGREGATION	$Tt \times Tt$ tall x tall	75% tall 25% short
INDEPENDENT ASSORTMENT	$RrGg \times RrGg$ round & green x round & green	9/16 round seeds & green pods  3/16 round seeds & yellow pods 3/16 wrinkled seeds & green pods 1/16 wrinkled seeds & yellow pods



# Incomplete Dominance and Codominance



# Incomplete Dominance

F1 hybrids have an appearance somewhat in between the phenotypes of the two parental varieties.

Example: snapdragons (flower)

red (RR) x white (rr)

RR = red flower

rr = white flower

	r	r
R		
R		

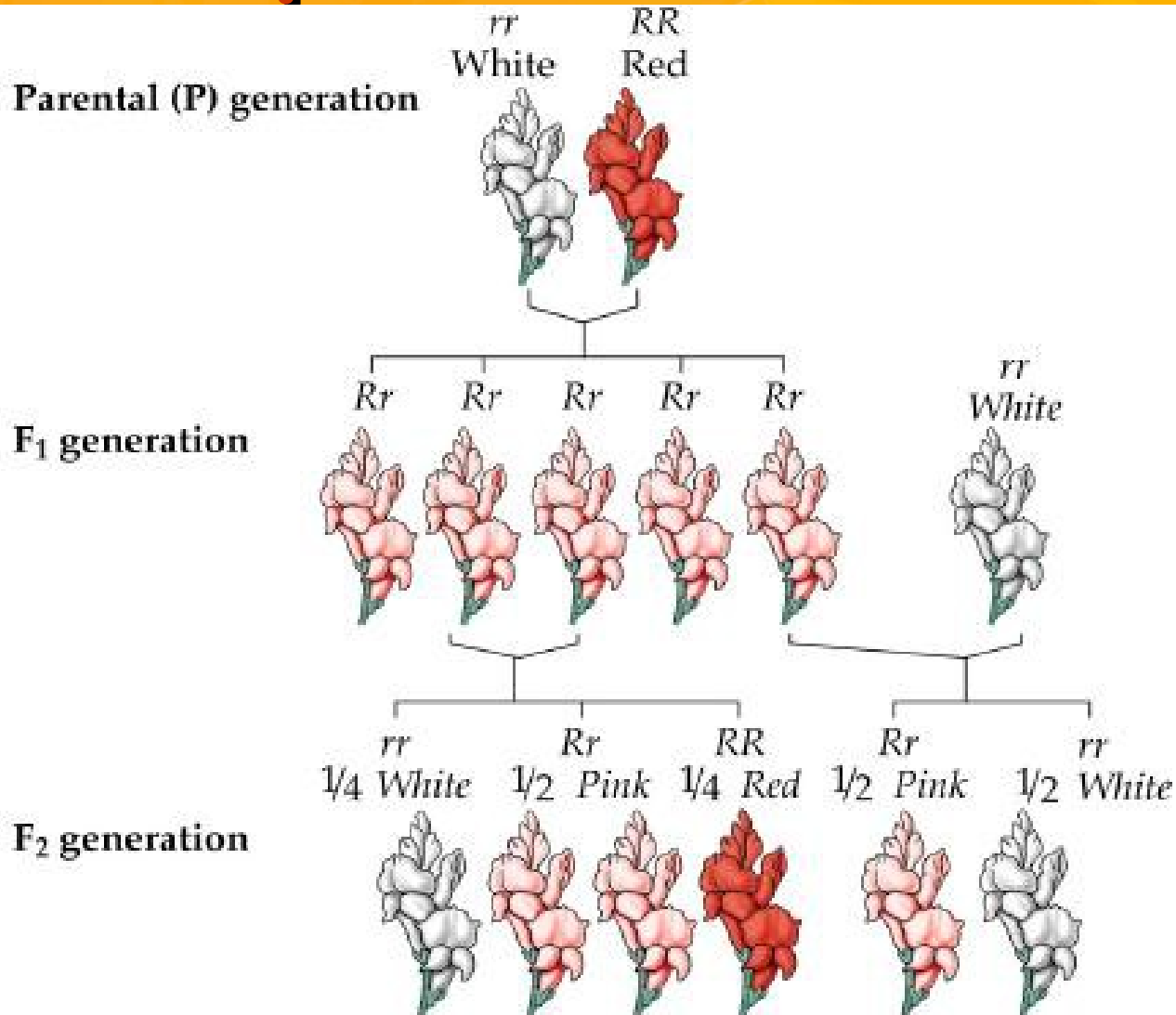
# Incomplete Dominance

	r	r
R	Rr	Rr
R	Rr	Rr

produces the  
 $F_1$  generation

All Rr = pink  
(heterozygous pink)

# Incomplete Dominance



© 1998 Sinauer Associates, Inc.



# Codominance

Two alleles are expressed (multiple alleles) in heterozygous individuals.

Example: blood type

1. type A =  $I^A I^A$  or  $I^A i$
2. type B =  $I^B I^B$  or  $I^B i$
3. type AB =  $I^A I^B$
4. type O =  $ii$

# Codominance Problem

**Example:** homozygous male Type B ( $I^B I^B$ )  
x  
heterozygous female Type A ( $I^A i$ )

	$I^A$	$i$
$I^B$	$I^A I^B$	$I^B i$
$I^B$	$I^A I^B$	$I^B i$

$$1/2 = I^A I^B$$

$$1/2 = I^B i$$

# Another Codominance Problem

- **Example:** male Type O (ii)

x

female type AB ( $I^A I^B$ )

$I^A$

$I^B$

i	$I^A i$	$I^B i$
i	$I^A i$	$I^B i$

$1/2 = I^A i$

$1/2 = I^B i$

# Codominance

## Question:

If a boy has a blood type O and his sister has blood type AB, what are the genotypes and phenotypes of their parents?

boy - type O (ii) X girl - type AB ( $I^A I^B$ )



# Codominance

Answer:

	$I^A$	$i$
$I^B$	$I^A I^B$	
$i$		$ii$

Parents:

genotypes =  $I^A i$  and  $I^B i$

phenotypes = A and B

# Sex-linked Traits

Traits (genes) located on the sex chromosomes

Sex chromosomes are X and Y

XX genotype for females

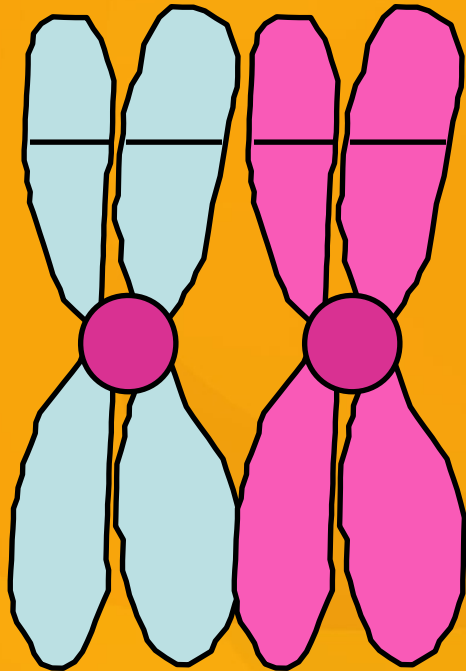
XY genotype for males

Many sex-linked traits carried on X chromosome

# Sex-linked Traits

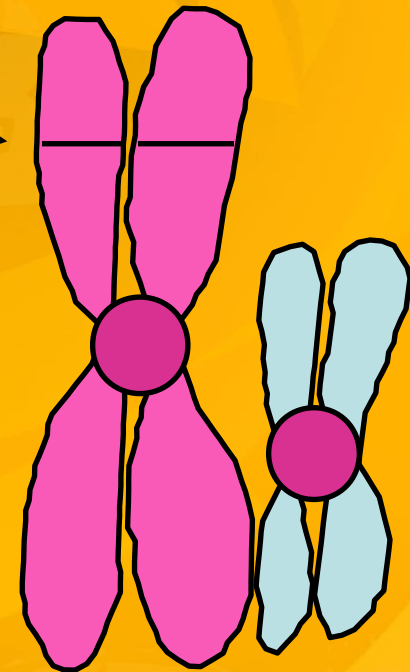
**Example:** Eye color in fruit flies

## Sex Chromosomes



**XX chromosome - female**

← **fruit fly** →  
**eye color**



**Xy chromosome - male**

# Sex-linked Trait Problem

Example: Eye color in fruit flies

(red-eyed male) x (white-eyed female)

$X^R Y$

x

$X^r X^r$

Remember: the Y chromosome in males does not carry traits.

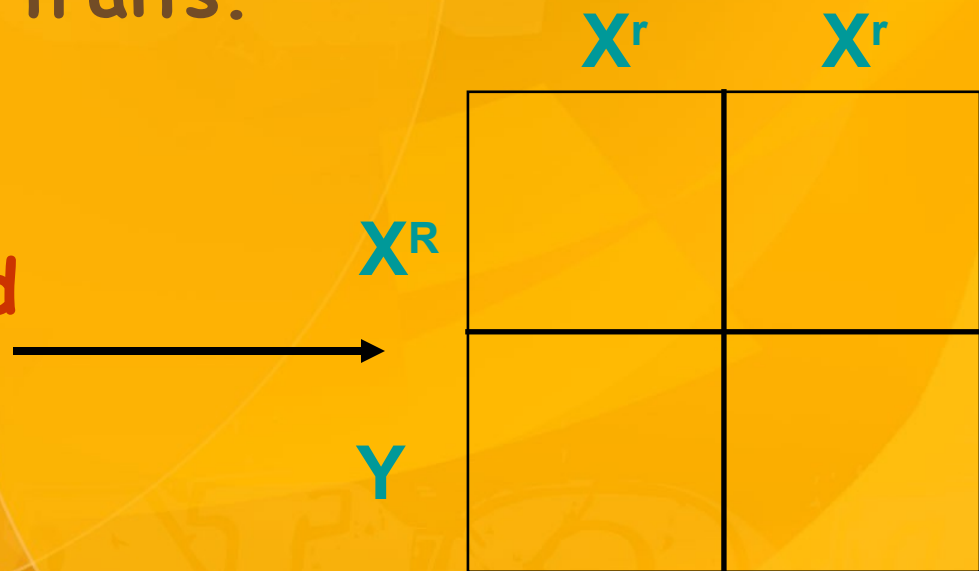
RR = red eyed

Rr = red eyed

rr = white eyed

XY = male

XX = female





# Sex-linked Trait Solution:

	$X^r$	$X^r$
$X^R$	$X^R X^r$	$X^R X^r$
$y$	$X^r y$	$X^r y$

50% red eyed  
female

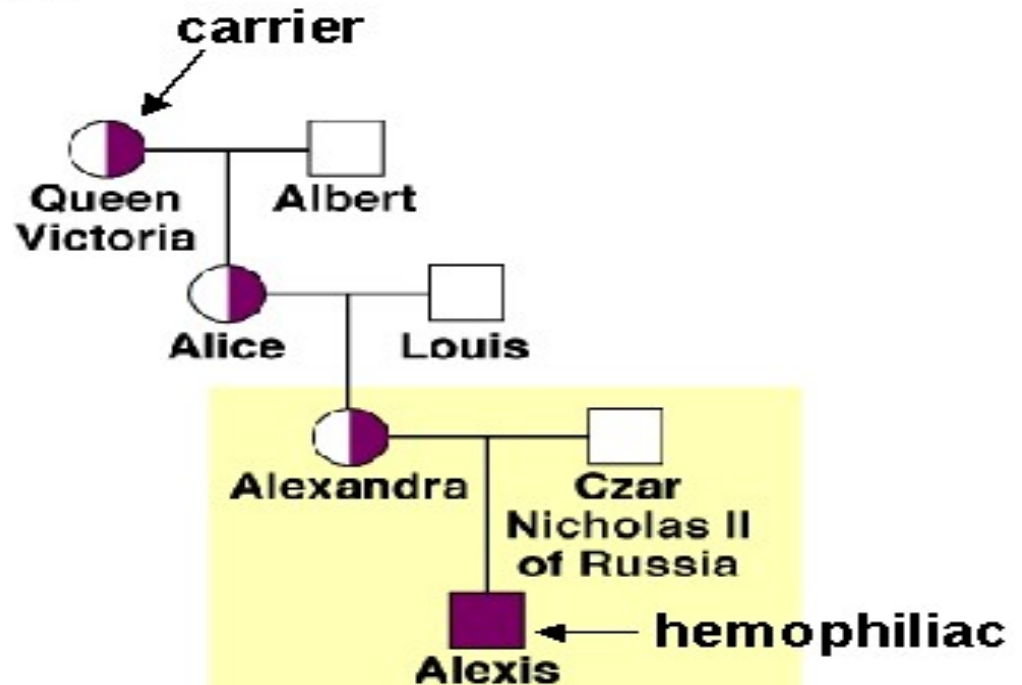
50% white eyed  
male

# Female Carriers

In a sex-linked trait (like hemophilia), women are carriers, and men have the phenotype more often.



©Addison Wesley Longman, Inc.



# Genetic Practice Problems

	T	t
T	TT	Tt
t	Tt	tt

# Breed the $P_1$ generation

tall (TT)  $\times$  dwarf (tt) pea plants

	t	t
T		
T		



# Solution:

tall (TT) vs. dwarf (tt) pea plants

	t	t	
T	Tt	Tt	}
T	Tt	Tt	

produces the  
**F<sub>1</sub> generation**

All Tt = tall  
(heterozygous tall)

# Breed the $F_1$ generation

tall ( $Tt$ ) vs. tall ( $Tt$ ) pea plants

	T	t
T		
t		

# Solution:

tall (Tt) × tall (Tt) pea plants

	T	t
T	TT	Tt
t	Tt	tt

produces the  
**F<sub>2</sub> generation**

1/4 (25%) = TT

1/2 (50%) = Tt

1/4 (25%) = tt

1:2:1 genotype

3:1 phenotype

